displays necessary for nominal operation and monitoring of the EMU systems. It was installed on the hard upper torso; its surfaces were faced with a thermal micrometeoroid garment, which contained the labels for the controls. The caution and warning system consisted of instrumentation and a microprocessor, which were used to obtain, process, and visually display information for use by the EVA crewmember in the operation and management of the EMU. Its functions involved display EMU leak check procedures, monitoring and display EMU consumables status, monitoring EMU operational integrity, and alerting crewmembers to EMU anomalies.[898]

IID. Mission Highlights and Discovery "Firsts"

OV-103, known as the "workhorse" of the SSP, flew thirty-nine missions between 1984 and 2011. In her twenty-seven years of service, *Discovery* was distinguished by a number of **"firsts**" and other significant accomplishments; twenty-seven missions included a new and/or noteworthy accomplishment. She was the first to complete twenty missions, marked by STS-63 (February 1995), and the only orbiter selected for NASA's RTF missions, STS-26 (September-October 1988) and STS-114 (July-August 2005), in the wake of the *Challenger* and *Columbia* accidents, respectively. Because of this, she is the only extant orbiter to have flown a designated test flight (STS-26, STS-114, STS-121). She is also the only extant orbiter to have flown successive missions multiple times (STS-51A, STS-51C, and STS-51D [1984-85]; STS-31 and STS-41 [1990]; STS-91 and STS-95 [1998]; and STS-114 and STS-121 [2005-06]).[899] Following the announced close of the SSP, *Discovery* was the first shuttle orbiter to complete transition and retirement processing.

In their "Major Milestones" chapter in *Wings in Orbit*, JSC Historian Jennifer Ross-Nazzal and co-author Dennis Webb, classify all shuttle missions into six major categories, noting that "categories are approximate as many missions feature objectives or payloads that can fit in multiple categories."[900] In accordance with this classification, *Discovery's* thirty-nine missions fall within the following groups, with the number of related missions noted:

- Classified DoD: four (4)
- Satellite deployment, retrieval, or repair: nine (9)
- Deployment or repair of interplanetary probes or observatories: five (5)
- Focus on science: six (6)
- Shuttle/*Mir* support: two (2)
- International Space Station support: thirteen (13)

[898] USA, *Crew Operations*, 2.11-7, 2.11-8.
[899] *Atlantis* is the only other extant orbiter to have flown successive missions (STS-101 and STS-106 [2000]). Chris Gebhardt, "After 26 Years;" Hale, *Wings In Orbit*, 527-29.
[900] Ross-Nazzal and Webb, "Major Milestones," 18.

These missions reflect the history of the SSP and its evolving priorities. During her first decade of service, *Discovery* released commercial satellites and DoD payloads into orbit. Missions throughout the 1990s focused on scientific advancements, including the deployment and servicing of the HST. Also during this decade, *Discovery* completed a pair of support missions to *Mir* as a prelude to the development of the ISS. Beginning in 1999, and continuing through her final flight in 2011, the missions of *Discovery* focused on the delivery of parts for ISS assembly, and the transport of crews and supplies. A list of Discovery's flights, with associated primary mission category, follows.

Space Shuttle *Discovery* Launch, Landing, and Mission Summary

SSP Flight No.	Mission No.	Orbiter/ Flight No.	Launch Date	Landing Date	Landing Site	Primary Mission Category
12	STS-41D	*Discovery* - 1	August 30, 1984	September 5, 1984	EAFB	Satellite
14	STS-51-A	*Discovery* - 2	November 8, 1984	November 16, 1984	KSC	Satellite
15	STS-51-C	*Discovery* - 3	January 24, 1985	January 27, 1985	KSC	DoD
16	STS-51-D	*Discovery* - 4	April 12, 1985	April 19, 1985	KSC	Satellite
18	STS-51-G	*Discovery* - 5	June 17, 1985	June 24, 1985	EAFB	Satellite
20	STS-51-I	*Discovery* - 6	August 27, 1985	September 3, 1985	EAFB	Satellite
26	STS-26	*Discovery* - 7	September 29, 1988	October 3, 1988	EAFB	Satellite
28	STS-29	*Discovery* - 8	March 13, 1989	March 18, 1989	EAFB	Satellite
32	STS-33	*Discovery* - 9	November 22, 1989	November 27, 1989	EAFB	DoD
35	STS-31	*Discovery* - 10	April 24, 1990	April 29, 1990	EAFB	Interplanetary probe or observatory
36	STS-41	*Discovery* - 11	October 6, 1990	October 10, 1990	EAFB	Interplanetary probe or observatory
40	STS-39	*Discovery* - 12	April 28, 1991	May 6, 1991	KSC	DoD
43	STS-48	*Discovery* - 13	September 12, 1991	September 18, 1991	EAFB	Interplanetary probe or observatory
45	STS-42	*Discovery* - 14	January 22, 1992	January 30, 1992	EAFB	Science
52	STS-53	*Discovery* - 15	December 2, 1992	December 9, 1992	EAFB	DoD
54	STS-56	*Discovery* - 16	April 8, 1993	April 17, 1993	KSC	Science
57	STS-51	*Discovery* - 17	September 12, 1993	September 22, 1993	KSC	DoD
60	STS-60	*Discovery* - 18	February 3, 1994	February 11, 1994	KSC	Science
64	STS-64	*Discovery* - 19	September 9, 1994	September 20, 1994	EAFB	Science

SSP Flight No.	Mission No.	Orbiter/ Flight No.	Launch Date	Landing Date	Landing Site	Primary Mission Category
67	STS-63	*Discovery* - 20	February 3, 1995	February 11, 1995	KSC	*Mir* support
70	STS-70	*Discovery* - 21	July 13, 1995	July 22, 1995	KSC	Satellite
82	STS-82	*Discovery* - 22	February 11, 1997	February 21, 1997	KSC	Interplanetary probe or observatory
86	STS-85	*Discovery* - 23	August 7, 1997	August 19, 1997	KSC	Science
91	STS-91	*Discovery* - 24	June 2, 1998	June 12, 1998	KSC	*Mir* support
92	STS-95	*Discovery* - 25	October 29, 1998	November 7, 1998	KSC	Science
94	STS-96	*Discovery* - 26	May 27, 1999	June 6, 1999	KSC	ISS support
96	STS-103	*Discovery* - 27	December 19, 1999	December 27, 1999	KSC	Interplanetary probe or observatory
100	STS-92	*Discovery* - 28	October 11, 2000	October 24, 2000	EAFB	ISS support
103	STS-102	*Discovery* - 29	March 8, 2001	March 21, 2001	KSC	ISS support
106	STS-105	*Discovery* - 30	August 10, 2001	August 22, 2001	KSC	ISS support
114	STS-114	*Discovery* - 31	July 26, 2005	August 9, 2005	EAFB	ISS support
115	STS-121	*Discovery* - 32	July 4, 2006	July 17, 2006	KSC	ISS support
117	STS-116	*Discovery* - 33	December 9, 2006	December 22, 2006	KSC	ISS support
120	STS-120	*Discovery* - 34	October 23, 2007	November 7, 2007	KSC	ISS support
123	STS-124	*Discovery* - 35	May 31, 2008	June 14, 2008	KSC	ISS support
125	STS-119	*Discovery* - 36	March 15, 2009	March 28, 2009	KSC	ISS support
128	STS-128	*Discovery* - 37	August 28, 2009	September 11, 2009	EAFB	ISS support
131	STS-131	*Discovery* - 38	April 5, 2010	April 20, 2010	KSC	ISS support
133	STS-133	*Discovery* -39	February 24, 2011	March 9, 2011	KSC	ISS support

Classified Department of Defense Missions

Between 1985 and 1992, *Discovery* flew four of the total ten classified DoD shuttle missions. These four missions were STS-51C, STS-33, STS-39, and STS-53. The missions broke from NASA's usually unclassified approach as launch times and payloads were kept secret, no astronaut interviews were allowed, and the media was not privy to air-to-ground communications.

Discovery's third flight, STS-51C, was the first SSP mission dedicated to the DoD. Because of the classified payload, little is known about the three-day mission in January 1985.[901] The USAF used the Inertial Upper Stage booster to deploy the payload, reportedly an eavesdropping satellite, ORION-1.[902] STS-31, *Discovery's* ninth flight, launched on November 22, 1989, was the fifth mission dedicated to the DoD. While unconfirmed, ORION-2, another eavesdropping satellite, may have been deployed.[903] STS-39, launched on April 28, 1991, was the first unclassified DoD mission, and the first time that flight details were released to the public. It included experiments sponsored by the USAF and the Strategic Defense Initiative.[904] The unclassified payload included Air Force Program-675 (AFP-675); Infrared Background Signature Survey (IBSS) with Critical Ionization Velocity (CIV), Chemical Release Observation (CRO) and Shuttle Pallet Satellite-II (SPAS-II) experiments; and Space Test Payload-1 (STP-1). Classified payload consisted of the Multi-Purpose Release Canister. Also on board was Radiation Monitorin Equipment III (RME III) and Cloud Logic to Optimize Use of Defense Systems-1A (CLOUDS-I).[905]

STS-53, *Discovery's* fifteenth flight and the final dedicated DoD mission of the SSP, launched on December 2, 1992. The partially classified payload included SDS B-3, assumed to be a data relay satellite.[906] *Discovery* also carried two unclassified secondary payloads and nine unclassified middeck experiments.[907]

Satellite Deployment, Retrieval, and Repair

Nine of *Discovery's missions*, launched between 1984 and 1995, were devoted to communication satellite deployment and repairs, including RTF-1 after the *Challenger* accident. These missions included STS-41D, -51A, -51D, -51G, -51I, -26, -29, -51, and -70. Communication satellites were *Discovery*'s main mission objective during her first two years of service. However, after the *Challenger* accident in 1986, "satellite retrieval and repair missions all but disappeared from the shuttle manifest."[908]

Three satellites were deployed on *Discovery's* maiden flight, STS-41D, launched on August 30, 1984. These included Satellite Business System SBS-D, SYNCOM IV-2 (also known as LEASAT2), and TELSTAR. The mission was nearly flawless, and the three satellites were

[901] NASA KSC, "STS-51C," November 23, 2007, http://www.nasa.gov/mission_pages/shuttle/shuttlemissions/archives/sts-51C.html; Boeing, *OV-103, Volume II*, 96.
[902] Cassutt, "Secret Space Shuttle," 3.
[903] Cassutt, "Secret Space Shuttle," 3.
[904] Rumerman, *U.S. Human Spaceflight*, 49.
[905] NASA KSC, "STS-39 (40)," June 29, 2001, http://science.ksc.nasa.gov/shuttle/missions/sts-39/mission-sts-39.html; Boeing, *OV-103, Volume II*, 100.
[906] Cassutt, "Secret Space Shuttle," 3.
[907] NASA KSC, "STS-53 (52)," June 29, 2001, http://science.ksc.nasa.gov/shuttle/missions/sts-53/mission-sts-53.html; Boeing, *OV-103, Volume II*, 102.
[908] Ross-Nazall and Webb, "Major Milestones," *25.*

successfully deployed. Also carried in the payload bay was an experimental 102' x 13' solar array, named the Office of Application and Space Technology, or OAST-1.[909] The knowledge gained from testing the device led to the arrays that later powered the ISS.[910] STS-41D also was the first flight to carry a commercially sponsored payload specialist.[911]

STS-51A was marked by the deployment of two satellites, Canadian communications satellite TELESAT-H (ANIK) and Defense communications satellite SYNCOM IV-I (also known as LEASAT-1).[912] In addition, two communications satellites, Palapa B-2 and Westar VI, were retrieved as separate EVAs. These satellites had been deployed nine months earlier, but failed to achieve their desired orbits. Astronauts Joseph Allen and Dale Gardner captured and secured both satellites in *Discovery's* payload bay.[913] This marked the first occasion satellites were retrieved from orbit and returned to Earth.[914]

Discovery deployed two communications satellites on her fourth flight, STS-51D, which launched on April 12, 1985, almost one month after the originally scheduled date. TELESAT-1 (ANIK C-1) was released satisfactorily, but SYNCOM IV-3 (also known as LEASAT-3) failed to activate. Two mission specialists were sent on an unplanned EVA in an unsuccessful effort to repair it.[915] The mission included two firsts: US Senator Jake Garn became the first member of Congress to fly aboard a shuttle, and astronauts participated in Toys in Space, an experiment targeted at schoolchildren.[916] The nearly seven-day flight concluded April 19 when *Discovery*'s front right tire blew while landing at KSC. The blown tire and extensive brake damage prompted the landing of future flights at Edwards AFB until implementation of the nose wheel steering system.

STS-51G, *Discovery*'s fifth flight, which launched on June 17, 1985, carried three communication satellites: MORELOS-A, for Mexico; ARABSAT-A, for Arab Satellite Communications Organization; and TELSTAR-3D, for AT&T. The crew included Prince Sultan

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[909] NASA KSC, "41-D (12)," June 29, 2001, http://science.ksc.nasa.gov/shuttle/missions/41-d/mission-41-d.html; NASA KSC, "STS-41D," February 18, 2010, http://www.nasa.gov/mission_pages/shuttle/shuttlemissions/archives/sts-41D.html.

[910] The rest of the cargo included: a large format camera; an IMAX camera to shoot footage later used in the film *The Dream Is Alive*; a Continuous Flow Electrophoresis System III, built by a pharmaceutical company; Radiation Monitoring Equipment; Shuttle Student Involvement Program experiments devised by high school students; and Cloud Logic to Optimize Use of Defense Systems, an Air Force experiment. NASA KSC, "STS-41D," February 18, 2010, http://www.nasa.gov/mission_pages/shuttle/shuttlemissions/archives/sts-41D.html.

[911] In 1983, NASA confirmed Charles D. Walker as the first industrial payload specialist. He was the first non-astronaut to fly on a shuttle. As a crew member, he accompanied the continuous flow electrophoresis equipment, developed for the McDonnell Douglas Corporation, on STS-41D, STS-51D, and STS-61B. NASA JSC, "Biographical Data, Charles D. Walker, February 1999, http://www.jsc.nasa.gov/Bios/PS/Walker.html.

[912] NASA KSC, "51-A (14)," June 29, 2001, http://science.ksc.nasa.gov/shuttle/missions/51-a/mission-51-a.html.

[913] Ross-Nazall and Webb, "Major Milestones," 23.

[914] NASA, *United States Space Shuttle Firsts*, 8.

[915] NASA KSC, "STS-51D," February 18, 2010, http://www.nasa.gov/mission_pages/shuttle/shuttlemissions/archives/sts-51D.html.

[916] NASA, *Space Shuttle Firsts*, 9.

Salman Al Saud of Saudi Arabia as a payload specialist, the first Arab and member of a royal family to travel to space.[917] During this mission, the Shuttle Pointed Autonomous Research Tool for Astronomy (SPARTAN) was released for the first time to survey the Milky Way galaxy.[918]

STS-51I, launched on August 27, was *Discovery's* third mission in 1985 that deployed communications satellites. Three satellites were deployed: ASC-1, for American Satellite Company; AUSSAT-1, an Australian Communications Satellite; and SYNCOM IV-4 also known as LEASAT-4), the Synchronous Communications Satellite. SYNCOM IV-4 failed to function after reaching geosynchronous orbit. Additionally, Mission Specialists William F. Fisher and James D.A. van Hoften retrieved, repaired, and redeployed LEASAT-3, originally deployed on mission STS-51-D.[919]

The primary payload carried aboard both missions STS-26 and STS-29, launched in September 1988, and March 1989, respectively, were NASA's Tracking and Data Relay Satellites, TDRS-C and TDRS-D. Each satellite was attached to an Inertial Upper Stage, which propelled them to a geosynchronous orbit.[920] STS-26 also was the first flight to use the redesigned SRBs, and the first to feature an all-veteran astronaut crew since the flight of Apollo 11.[921]

Discovery's seventeenth flight, STS-51, launched on September 12, 1993, after numerous delays, deployed the Advanced Communications Technology Satellite, or ACTS. This satellite served as a test bed for advanced communications satellite concepts and technology. Its Transfer Orbit Stage booster was used for the first time to propel a communications satellite into geosynchronous altitude on the first day of the mission. The first attempt to deploy ACTS was delayed when two-way communications were temporarily lost with Mission Control.[922] It also marked the first time a Shuttle payload was controlled from KSC.[923] The mission ended with the first nighttime shuttle landing at KSC.

The last *Discovery* mission to deploy a satellite was STS-70, launched on July 13, 1995. The primary objective was to release the seventh TDRS satellite, TDRS-G, and the sixth placed in operational use. The deploy operations used three separate control centers to manage orbit operations. The White Sands ground station controlled the TDRS, the JSC Mission Control Center controlled the shuttle, and the booster stage was controlled from Onizuka AFB in

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[917] Gebhardt, "After 26 Years;" Rumerman, *U.S. Human Spaceflight*, 44-45.
[918] NASA KSC, "STS-51-G (18)," June 29, 2001, http://science.ksc.nasa.gov/shuttle/missions/51-g/mission-51-g.html.
[919] NASA KSC, "STS-51-I (20)," June 29, 2001, http://science.ksc.nasa.gov/shuttle/missions/51-i/mission-51-i.html.
[920] NASA KSC, "STS-26," February 18, 2010, http://www.nasa.gov/mission_pages/shuttle/shuttlemissions/archives/sts-26.html; NASA KSC, "STS-29," August 30, 2008, http://www.nasa.gov/mission_pages/shuttle/shuttlemissions/archives/sts-29.html.
[921] Rumerman, *U.S. Human Spaceflight*, 46.
[922] NASA KSC, "STS-51 (57)," June 29, 2001, http://science.ksc.nasa.gov/shuttle/missions/sts-51/mission-sts-51.html.
[923] This payload was the Orbiting and Retrievable Far and Extreme Ultraviolet Spectrograph-Shuttle Pallet Satellite, a joint German-US astrophysics payload. Rumerman, *U.S. Human Spaceflight*, 54.

Sunnyvale, California. This mission marked the completion of NASA's TDRS system that provided communication, tracking, telemetry, data acquisition, and command services to the shuttle and other low-orbital spacecraft missions.[924] STS-70 was the first time a Space Shuttle flew with the new Block I SSME, which featured improvements that increased their stability and safety.[925]

Deployment and Repair of Interplanetary Probes and Observatories

Discovery flew five missions between 1990 and 1999 that included the deployment or repair of interplanetary probes and observatories, the most notable of which was the Hubble Space Telescope (HST). The HST is the "first large optical telescope ever to be placed above Earth's atmosphere and the first of NASA's Great Observatories."[926] *Discovery* deployed the telescope in 1990, and returned to the HST for two of the five servicing missions; *Columbia*, *Atlantis*, and *Endeavour* each flew one servicing mission. The vehicle's other two space science missions included the release of the *Ulysses* observatory and the Upper Atmospheric Research Satellite interplanetary probe.

Discovery deployed the HST during STS-31, the vehicle's tenth flight. The mission was first scheduled for April 18, 1990, but that date was moved forward to April 10, marking the first time a shuttle launch was expedited.[927] However, the launch that day was scrubbed when the orbiter's APU failed. Rescheduled for April 24, a malfunctioning LO2 valve briefly held up liftoff before *Discovery* launched.[928] Because of the need to place the HST above most of the atmosphere, the orbiter reached an altitude of 329.22 statute miles, the highest shuttle orbit at that time.[929] The HST was deployed on the second day of the mission, but a faulty sensor delayed the release of one of the solar arrays needed to power the telescope. Carbon brakes were used on an orbiter for the first time when *Discovery* touched down on April 29 at Edwards AFB.[930]

Subsequently, in 1997 and 1999, *Discovery* flew two servicing missions to repair the HST. The first, STS-82, was launched on February 11, 1997. This was the second in a series of planned servicing missions; the first was performed by the *Endeavour* crew on STS-61 (December 1993). Two older instruments, the Goddard High Resolution Spectrometer and the Faint Object Spectrograph, were removed. Two new astronomy instruments were installed: the Space Telescope Imaging Spectrograph (STIS) and the Near Infrared Camera and Multi-Object Spectrometer (NICMOS). In addition, other existing hardware was replaced with upgrades and

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[924] Rumerman, *U.S. Human Spaceflight*, 58.
[925] NASA KSC, "STS-70 (70)," June 29, 2001, http://www.nasa.gov/shuttle/missions/sts-70/mission-sts-70.html.
[926] Rumerman, *U.S. Human Spaceflight*, 48.
[927] Jenkins, *Space Shuttle*, 297.
[928] NASA KSC, "STS-31 (35)," June 29, 2001, http://science.ksc.nasa.gov/shuttle/missions/sts-31/mission-sts-31.html.
[929] Rumerman, *U.S. Human Spaceflight*, 48.
[930] NASA, *Space Shuttle Firsts*, 13; Rumerman, *U.S. Human Spaceflight*, 48; Carol Christian, Kamlesh Lulla, and David Leckrone, "The Space Shuttle and Great Observatories," in Hale, *Wings In Orbit.*

spares. The HST received a refurbished Fine Guidance Sensor to provide pointing information for the spacecraft; it was also used as a scientific instrument for astrometric science. A reel-to-reel tape recorder was replaced with a Solid State Recorder. One of four Reaction Wheel Assemblies (RWAs) was replaced with a refurbished spare. The RWAs help move the telescope into position and also maintain the position of the spacecraft.[931] The mission included five EVAs, which totaled thirty-three hours and eleven minutes.

STS-103, *Discovery*'s twenty-seventh mission and second servicing mission to the HST, launched on December 19, 1999, after several delays. Four EVAs were scheduled to renew and refurbish the telescope. Since the last servicing mission flown in February 1997, three gyroscopes had failed (in 1997, 1998, and 1999, respectively). During the STS-103 mission, all six gyroscopes were replaced. Also, the Fine Guidance Sensor was replaced with a refurbished unit that was returned from the second servicing mission. The spacecraft's computer was replaced, and a new voltage/temperature kit was installed to prevent battery overcharging and overheating. A new transmitter, solid state recorder, and S-Band Single Access Transmitter (SSAT) also were installed. New thermal insulation blankets were added to replace the degraded outer insulation. [932]

Discovery's eleventh flight, STS-41, launched on October 6, 1990, deployed *Ulysses*, an ESA-built deep space probe, to study the polar regions of the sun. Two upper stages, the Inertial Upper Stage and a mission-specific Payload Assist Module-S, combined for the first time to send *Ulysses* toward out-of-ecliptic trajectory.[933] The following year, STS-48, launched on September 12, 1991, deployed the Upper Atmospheric Research Satellite to study the Earth's stratosphere, mesosphere, and lower thermosphere.[934] The satellite was a component of NASA's Earth Science Enterprise program, an initiative to better understand how humans affect the planet.

Science Research

During the 1990s, Spacelab and SPACEHAB modules carried data-collecting satellites aboard *Discovery.* Beginning with STS-42 in 1992, experiments in areas such as life, Earth, and material sciences were the primary manifest for six *Discovery* missions.[935] These included STS-42, -56, -60, -64, -85, and -95.

STS-42, *Discovery*'s fourteenth flight, began on January, 22, 1992. It carried the International Microgravity Laboratory-1, a pressurized manned Spacelab module. The mission objective was to explore in depth the complex effects of weightlessness on living organisms and materials

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[931] NASA KSC, "STS-82 (82)," June 29, 2001, http://science.ksc.nasa.gov/shuttle/missions/sts-82/mission-sts-82.html.
[932] NASA KSC, "STS-103 (96)," June 29, 2001, http://science.ksc.nasa.gov/shuttle/missions/sts-103/mission-sts-103.html.
[933] NASA KSC, "STS-41 (36)," June 29, 2001, http://science.ksc.nasa.gov/shuttle/missions/sts-41/mission-
[934] Rumerman, *U.S. Human Spaceflight*, 50.
[935] Ross-Nazzal and Webb, "Major Milestones," 27.

processing. The crew divided into two teams to conduct experiments on the human nervous system's adaptation to low gravity and the effects of microgravity on other life forms. Low-gravity materials processing experiments included crystal growth from a variety of substances. The mission was extended one day to finish additional experiments.[936]

Discovery's sixteenth flight, STS-56, began on April 8, 1993, two days later than planned. The flight's primary payload was the Atmospheric Laboratory for Applications and Science (ATLAS-2), designed to collect data on the relationship between the sun's energy output and the Earth's middle atmosphere, and how these factors affect the ozone layer. ATLAS-2 was one element of NASA's Mission to Planet Earth program. All seven ATLAS-2 instruments were first flown on ATLAS-1 during the STS-45 mission flown by *Atlantis* in March 1992. The STS-56 crew also deployed the SPARTAN-201, a free-flying science instrument platform designed to study velocity and acceleration of solar wind and to observe the sun's corona. In addition, experiments were done on microgravity and tissue loss in space.[937] STS-56 also marked the first contact between a Shuttle and *Mir* using amateur radio equipment.

Discovery's eighteenth mission, STS-60, which launched on February 3, 1994, and returned on February 11, carried a variety of SPACEHAB module experiments. These included the Organic Separations payload, designed to investigate cell separation techniques for possible pharmaceutical and biotechnology processing, and the Equipment for Controlled Liquid Phase Sintering Experiment package, a furnace designed to study stronger, lighter and more durable metals. Other experiments included the Three-Dimensional Microgravity Accelerometer, Astroculture, Bioserve Pilot Lab, Commercial Generic Bioprocessing Apparatus, Commercial Protein Crystal Growth, Controlled Liquid Phase Sintering, and Immune Response Studies, among others. Another primary mission payload was the Wake Shield Facility, used to grow innovative thin film materials for use in electronics.[938]

STS-64, *Discovery*'s nineteenth mission, launched on September 9, 1994, carried the Lidar in Space Technology Experiment (LITE), which was used to perform atmospheric research. This was the first flight of LITE, which involved the use of lasers for environmental research. During the mission, the crew also released and retrieved the SPARTAN-201. The flight included the first untethered EVA since *Discovery*'s STS-51-A ten years earlier.[939]

Discovery's twenty-third mission, STS-85, launched on August 7, 1997, was dedicated to scientific experiments and testing hardware for the ISS. The primary mission was to deploy and retrieve the Cryogenic Infrared Spectrometers and Telescopes for the Atmosphere-Shuttle Pallet

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[936] NASA KSC, "STS-42 (45)," June 29, 2001, http://science.ksc.nasa.gov/shuttle/missions/sts-42/mission-sts-42.html.
[937] NASA KSC, "STS-56 (54)," June 29, 2001, http://science.ksc.nasa.gov/shuttle/missions/sts-56/mission-sts-56.html.
[938] NASA KSC, "STS-60 (60)," June 29, 2001, http://science.ksc.nasa.gov/shuttle/missions/sts-60/mission-sts-60.html.
[939] Rumerman, *U.S. Human Spaceflight*, 56.

Satellite-2 (CRISTA-SPAS-2), previously flown on STS-66 in 1994. It was the fourth in a series of cooperative ventures between the German Space Agency and NASA. This payload measured trace gases and dynamics of the Earth's middle atmosphere. CRISTA-SPAS-2 flew for about 200 hours before *Discovery*'s crew retrieved it. A number of experiments were conducted throughout the mission, including the study of a robotic arm created by the Japanese Space Agency for use on the ISS.[940]

Astronaut John Glenn gained fame in 1962 when he was the first American to orbit Earth. Thirty-eight years later, Glenn, then a 77-year-old United States senator, returned to space as a payload specialist for STS-95, *Discovery*'s twenty-fifth mission. The effect of microgravity on human aging was studied. The launch on November 29, 1998, was witnessed by President Bill Clinton, a first for a sitting president.[941] The primary objectives of the mission were to conduct a variety of science experiments in the pressurized SPACEHAB module, focusing on life sciences, microgravity sciences and advanced technology. In addition, the SPARTAN satellite was deployed and retrieved to study the sun. The crew also tested components planned for installation on the HST during the next servicing mission.[942]

Mir Support

Two *Discovery* missions, STS-63 in 1995 and STS-91 in 1998, supported the Shuttle/*Mir* Program. The first was to practice a rendezvous with the Russian space station, and the second marked the last time a shuttle docked with the station.[943]

STS-63 launched without incident on February 3, 1995. The primary focus of the mission was to perform a rendezvous and fly around of *Mir* to verify flight techniques, communications, and navigation sensor interfaces, and engineering analyses associated with shuttle/*Mir* proximity operations in preparation for future docking missions.[944] *Discovery* came within just 37' of *Mir*, and photographs taken by the space station's crew marked the first time a shuttle was captured on film in space from another manned spacecraft. *Discovery*'s payload included the SPARTAN-204, which was deployed and successfully retrieved. STS-63 is associated with a number of "firsts," including the first spacewalk by an African American, Mission Specialist Bernard Harris, and the first female shuttle pilot, Eileen Collins.[945] Also, with this flight, *Discovery* became the first orbiter to complete twenty missions.

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[940] NASA KSC, "STS-85 (86)," June 29, 2001, http://science.ksc.nasa.gov/shuttle/missions/sts-85/mission-sts-85.html; Rumerman, *U.S. Human Spaceflight*, 62.
[941] John Glenn's presence drew a lot of media attention, and the crew was interviewed by CBS news anchor Walter Cronkite and *The Tonight Show* host Jay Leno while in orbit.
[942] NASA KSC, "STS-95 (92)," June 29, 2001, http://science.ksc.nasa.gov/shuttle/missions/sts-95/mission-sts-95.html.
[943] Ross-Nazzal and Webb, "Major Milestones," 27.
[944] NASA KSC, "STS-63 (67)," June 29, 2001, http://science.ksc.nasa.gov/shuttle/missions/sts-63/mission-sts-63.html.
[945] Rumerman, *U.S. Human Spaceflight*, 53.

STS-91, *Discovery*'s sole mission to *Mir*, was the ninth and last time an orbiter docked with the Russian space station. The goal of this mission was to bring home Andrew Thomas, the seventh and final American astronaut to live aboard *Mir;* Thomas spent 130 days aboard the station. When *Discovery* launched on June 2, 1998, her payload held the SPACEHAB module, which contained supplies for *Mir*'s crew. The payload also contained an Alpha Magnetic Spectrometer, built by an international team of researchers to study the universe. The shuttle's robotic arm's new electronics and software were tested in preparation for the construction of the ISS.[946] After the orbiter docked with *Mir*, cargo was exchanged and Thomas boarded *Discovery* for the flight back to Earth. STS-91 also marked the first use of the new super lightweight tank.[947]

International Space Station Support

Discovery flew thirteen of her final fourteen missions to construct, supply, and exchange crews with the space station.[948] Two of these ISS support missions were part of RTF-2. *Discovery*'s goal for STS-96, her twenty-sixth flight, was to transport supplies to the as yet unmanned station. The shuttle launched on May 27, 1999, and carried the SPACEHAB module packed with equipment. She also carried both a U.S-built crane and a Russian-built crane, which were installed on the station. The STARSHINE satellite, partially built by an international group of high school students, was successfully deployed during the flight. Three days into the mission, *Discovery* became the first orbiter to dock with the ISS, and 3,567 pounds of supplies were unloaded. The crew also installed two new portable foot restraints, and attached three bags of tools and handrails to aid future ISS assembly operations.[949] After undocking, *Discovery* performed a flyaround of the ISS to obtain a detailed photographic record.[950]

STS-92, *Discovery*'s twenty-eighth flight, was the 100th mission of the SSP and included the 100th spacewalk. The orbiter launched on October 11, 2000, after four days of delays. *Discovery* carried the Zenith Port, or Z1, truss structure, which was installed on top of the *Unity* connecting node, and also delivered the Pressurized Mating Adaptor 3 (PMA-3), which was used as a docking port. After successful completion of four EVAs to attach the truss and set up the power supply, the shuttle landed at Edwards AFB on October 24, delayed two days because of bad weather.[951]

OV-103's twenty-ninth mission, STS-102, began at sunrise on March 8, 2001. The primary objectives of this mission were to replace the Expedition 1 crew and to unload supplies, equipment and science racks from the *Leonardo* MPLM. The crew attached a coolant pump and

[946] Rumerman, *U.S. Human Spaceflight*, 64.
[947] Gebhardt, "After 26 Years;" Rumerman, *U.S. Human Spaceflight*, 64.
[948] Duggins, *Final Countdown*, 112-161.
[949] NASA KSC, "STS-96 (94)," June 29, 2001, http://science.ksc.nasa.gov/shuttle/missions/sts-96/mission-sts-96.html.
[950] Rumerman, *U.S. Human Spaceflight*, 65.
[951] NASA KSC, "STS-92 (100)," June 29, 2001, http://science.ksc.nasa.gov/shuttle/missions//sts-92/mission-sts-92.html.

an External Storage Platform to the outside of the *Destiny* module.[952] *Discovery's* next mission, STS-105, launched on August 10, 2001, also carried the *Leonardo* MPLM, which contained additional scientific racks, equipment, and supplies. Another payload was the Materials International Space Station Experiments (MISSE), a project to fly materials and other types of space exposure experiments on the station. The MISSE experiments were the first externally mounted experiments conducted on the ISS.[953] During two spacewalks, the Early Ammonia Servicer was installed to provide a backup source of energy supply to the ISS, and heater cables and handrails were attached for the station's Starboard-zero (S0) truss structure, which was scheduled for delivery on a future mission. ISS Expedition Crew 2 was replaced by Expedition Crew 3.

After the *Columbia* accident on February 1, 2003, *Atlantis* originally was selected for RTF-2. However, corrosion was discovered on *Atlantis*' rudder speed brake system. Although *Discovery* had the same problem, NASA engineers calculated that OV-103's brakes could be fixed more quickly. Thus, *Discovery* was chosen to fly STS-114, her thirty-first flight and the first of two RTF-2 test missions. Following delays, *Discovery* finally lifted off on July 26, 2005. *Discovery's* flight was extensively documented through a system of new and upgraded ground-based and airborne cameras, as well as radar systems, laser systems on the OBSS, and sensors in the shuttle's wings. The primary objectives of this mission were to test and evaluate new safety procedures, and to conduct assembly and maintenance tasks on the ISS. On flight day three, the orbiter executed a rendezvous pitch maneuver, which flipped the shuttle end over end, allowing the crew to photograph the underside of *Discovery* and her heat-resistant tiles in detail. The payload included scientific experiments contained within the *Raffaello* MPLM. During the first two EVAs, in-orbit shuttle repair techniques were tested and work was completed on the space station. A third EVA tasked the crew with the first on-orbit repair of the shuttle heat shield, which entailed the removal of two protruding gap fillers.[954]

STS-121, the second RTF test flight, launched on July 4, 2006. This mission demonstrated techniques for inspection and protection of the shuttle's TPS and replacement of critical hardware needed for future ISS assembly. *Discovery*'s crew unloaded about 7,400 pounds of equipment and supplies from the *Leonardo* MPLM, including a new heat exchanger for the common cabin air assembly, a new window and window seals for the Microgravity Sciences Glovebox, and a spare EVA suit and emergency jetpack. This mission restored the station to a three-person crew for the first time since May 2003. It was also the most photographed shuttle mission in history.[955]

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[952] Rumerman, *U.S. Human Spaceflight*, 68; NASA KSC, "STS-102 (103)," July 25, 2001, http://science.ksc.nasa.gov/shuttle/missions/sts-102/mission-sts-102.html.
[953] NASA KSC, "STS-105 (106)," October 2, 2001, http://science.ksc.nasa.gov/shuttle/missions/sts-105/mission-sts-105.html.
[954] NASA, "STS-114," November 23, 2007, http://www.nasa.gov/mission_pages/shuttle/shuttlemissions/archives/sts-114.html.
[955] NASA, "STS-121," November 23, 2007, http://www.nasa.gov/mission_pages/shuttle/shuttlemissions/archives/sts-121.html.

Discovery's thirty-third mission, STS-116, was among her most challenging. After a two-day weather delay, the spacecraft lifted off at 8:47 p.m. on December 9, 2006, the first night launch since the *Columbia* accident. *Discovery* carried several tons of equipment and supplies, most of which was contained in the SPACEHAB module. During four spacewalks, the crew added the P5 spacer truss segment, rewired the station's power system to support the ISS's final configuration and arrival of additional modules, and retracted the solar arrays that had folded improperly.[956]

Discovery began STS-120 on October 23, 2007, the shuttle's thirty-fourth flight. The payload bay held the Harmony Node 2 module that was used to connect the ISS to two laboratories. For the first time in history, both the Space Shuttle commander and ISS commander were women: Pamela Melroy on *Discovery* and Peggy Whitson on the ISS. The mission included an ISS crew exchange, and a risky spacewalk was completed to repair a torn solar array using improvised tools.[957] To maximize their time in orbit, *Discovery*'s crew reentered the atmosphere over the middle of the United States by the descending node reentry, a maneuver of descent discouraged after the *Columbia* accident.[958]

The goal of *Discovery*'s thirty-fifth mission, STS-124, was to deliver *Kibo*, the 32,500-pound Japanese Aerospace Exploration Agency's (JAXA) pressurized module, to the ISS. This mission was the second of three flights that brought components to complete the *Kibo* laboratory. The module was so large that *Discovery*'s orbiter boom was left at the ISS during STS-120 to provide sufficient space in the orbiter's payload bay. STS-124 marked the first time the JAXA flight control team activated and controlled a module from Kibo Mission Control in Tsukuba, Japan. In the third and final mission spacewalk, astronauts exchanged a depleted nitrogen tank, and removed thermal covers and launch locks from the newly installed *Kibo* hardware, and reinstalled a repaired television camera to the left P1 truss.[959]

STS-119, launched on March 15, 2009, was the 100th SSP mission since the *Challenger* accident. *Discovery* delivered two solar arrays and the S6 truss, which were installed during three EVAs. This addition expanded the capacity of the ISS, and enabled an increase from three to six resident astronauts. The crew also repaired the station's water recycling system before returning to KSC on March 27 after a crew exchange.[960] *Discovery's* next mission, STS-128, launched on August 28, 2009. The lift off for STS-128 was delayed a day by weather and then three more

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[956] Anna Heiney, "STS-116 Delivers Permanent Power," December 22, 2006, http://www.nasa.gov/mission_pages/shuttle/shuttlemissions/sts116/launch/sts116_summary.html; NASA, "STS-116," April 2, 2008, http://www.nasa.gov/mission_pages/shuttle/shuttlemissions/sts116/main/index.html.
[957] NASA, "STS-120 (23rd Space Station Flight)," *NASA Facts*, 2007, http://www.nasa.gov/pdf/216375main_STS-120.pdf.
[958] Gebhardt, "After 26 Years."
[959] Anna Heiney, "*Discovery* Delivers a Module 'Filled With Dreams,'" June 19, 2008, http://www.nasa.gov/mission_pages/shuttle/shuttlemissions/sts124/launch/124_overview.html; NASA, "STS-124," June 20, 2008, http://www.nasa.gov/mission_pages/shuttle/shuttlemissions/sts124/launch/124_overview.html.
[960] Elaine M. Marconi, "NASA's STS-119 Mission: Boosting the Station Power," April 6, 2009, http://www.nasa.gov/mission_pages/shuttle/behindscenes/119_overview.html; NASA, "STS-119 Mission Information," April 16, 2009, http://www.nasa.gov/mission_pages/shuttle/shuttlemissions/sts119/main/index.html.

days by a faulty fuel valve on the ET. The *Leonardo* MPLM carried support racks, science racks, a freezer for sample storage, a new sleeping compartment, and the COLBERT, the Combined Operational Load Bearing External Resistance Treadmill. STS-128 also included an ISS crew member exchange. After three ISS maintenance EVAs, *Discovery* landed at Edwards AFB on September 11, delayed a day because of poor weather.[961]

Discovery's thirty-eighth mission began on April 5, 2010. STS-131 accomplished several milestones, including the last nighttime shuttle launch, the first time four women were in space together, the last SSP flight to include first-time astronauts, and the first time two Japanese astronauts were in space together.[962] *Discovery* carried the *Leonardo* MPLM containing over 17,000 pounds of supplies and equipment. During three EVAs, the crew replaced an ammonia tank assembly, retrieved a Japanese experiment, and switched out a rate gyro assembly on the S0 truss element. The Ku-band data transmission system failed to work once in orbit.[963] *Discovery* returned to KSC on April 20 after a day's delay.[964] The STS-131 mission lasted fifteen days, two hours, forty-seven minutes, and ten seconds, *Discovery's* longest duration flight.

Discovery's final flight, STS-133, was originally scheduled to launch on November 1, 2010. However, due to a variety of problems, including an O-ring seal failure, failure of the SSME-3 redundant controller, an ET leak, and damaged ET stringers, the launch date was incrementally pushed up to February 24, 2011.[965] The crew for STS-133 included Commander Steve Lindsey; Pilot Eric Boe; and Mission Specialists Michael Barratt, Nicole Stott, Alvin Drew, and Steve Bowen. Bowen replaced Tim Kopra, who was injured a month before *Discovery* launched. *Discovery*'s payload included Robonaut 2, the first human-like robot in space. Similar to a human in appearance and movement, Robonaut 2 was built to assist astronauts aboard the ISS with commonplace or dangerous tasks. OV-103 also carried the Permanent Multipurpose Module (converted from the *Leonardo* module), which contained scientific experiments and provided the ISS with storage space, and the Express Logistics Carrier 4, an external platform that holds large equipment. The crew unloaded the cargo, attached the Permanent Multipurpose Module, the last permanent pressurized piece of the ISS, and completed maintenance and repairs on the ISS during a pair of spacewalks. After extending her stay two days, *Discovery* landed at KSC on March 9 and became the first Space Shuttle to retire after a flight of twelve days, nineteen hours, four minutes and fifty seconds.[966]

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[961] Steve Siceloff, "STS-128 Outfits Station for New Science," September 23, 2009, http://www.nasa.gov/mission_pages/shuttle/shuttlemissions/sts128/launch/128_overview.html.
[962] Gebhardt, "After 26 Years."
[963] NASA, "STS-131 Mission Information," April 27, 2010, http://www.nasa.gov/mission_pages/shuttle/shuttlemissions/sts131/main/index.html.
[964] Cheryl L. Mansfield, "STS-131: Teamwork Overcomes Mission's Challenges," April 23, 2010, http://www.nasa.gov/mission_pages/shuttle/shuttlemissions/sts131/launch/131mission_overview.html.
[965] Gebhardt, "After 26 Years."
[966] NASA, "STS-133 Mission Information," March 15, 2011, http://www.nasa.gov/mission_pages/shuttle/shuttlemissions/sts133/main/index.html.